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The Role of Flight Progress Strips in En Route Air Traffic Control: A Time-Series Analysis

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16. Abstract

Paper flight progress strips (FPSs) are currently used in the United States en route air traffic control system to document flight information. Impending automation will replace these paper strips with electronic flight data entries. In this observational study, control actions, communication events, and computer interactions were recorded and analyzed using time-series regression models. Regression models were developed to predict FPS activities (Writing, Manipulating, Looking) at different levels of traffic complexity, for individuals and teams of air traffic controllers. Results indicated that writing was well predicted by a common, simple time-series equation. The ability to predict FPS manipulations was modest, but prediction of looking at FPSs was poor. Overall, these data indicate that (1) flight strip activities were similar for individuals and for the data-side controllers in the team (whose primary responsibility is the strips), and (2) flight strip activity for teams was predictable from the radar-side controller's actions, but not the data-side controller's actions.

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The Role of Flight Progress Strips in En Route Air Traffic Control: A Time-Series Analysis

In the United States, there are 21 en route air traffic control centers operated by the Federal Aviation Administration, primarily responsible for the safe and efficient flight of high-speed, high-altitude aircraft between takeoff and landing. The airspace assigned to an en route center is divided into multiple sectors, each handled my an individual controller or by a team of two controllers[1]: The radar-side (R-side) controller is primarily responsible for observing the radar screen and communicating with pilots; the data-side (D-side) controller, seated next to the R-side, assumes primary responsibility for preplanning and updating of flight information. Although this general rule is true for most facilities, there are situations in which the responsibilities of the D-side controller are changed due to R-side requests.

Anticipated automation, to be implemented in the 1990s, will drastically affect D-side responsibilities. The first stage of the automation is the Initial Sector Suite System (ISSS). The implementation of ISSS will significantly change the display of, and interaction with, flight information (Ammerman & Jones, 1988). Flight information is currently displayed on paper flight progress strips (FPSs) that enable controllers to update and manipulate flight information manually; under ISSS, flight information will be displayed on a computer screen as electronic flight data entries (FDEs) that will require controllers to interact with flight information using a keyboard and trackball.

The FPS is a rectangular piece of paper that contains detailed flight information based on the projected altitudes, routes, and arrival times submitted by the pilot (see Figure 1). The FPSs are mounted in a bay of plastic holders next to the radar display. As an aircraft enters a controller's sector, its corresponding FPS is moved from the "suspense" bay into the "active" bay, which contains the FPSs of all aircraft in the sector. As the flight moves through the sector, the FPS is continually updated by writing on it, sequencing it among the other strips, or it is used as a memory aid by offsetting ("cocking") it from the other strips. Besides providing a legal record of the flight, the updated flight strip may also supply information and decision support for the controller.

Because of the important role of FPSs, several investigators have voiced concern regarding their conversion to an electronic format. For example, the active manipulation of the strip or deciding where to insert a strip when moving it from the active to suspense bay may force the integration of the strip into the existing situation, thereby serving as a memory aid (Hopkin, 1988). The organization of strips within the bay may also be informative about the scheduling of work tasks (Shapiro, Hughes, Randall, & Harper, 1991), thus providing an indication of impending traffic loads. Once the strips have been moved into the active bay, they may be manipulated and sequenced among the other strips. Attention can be drawn to a

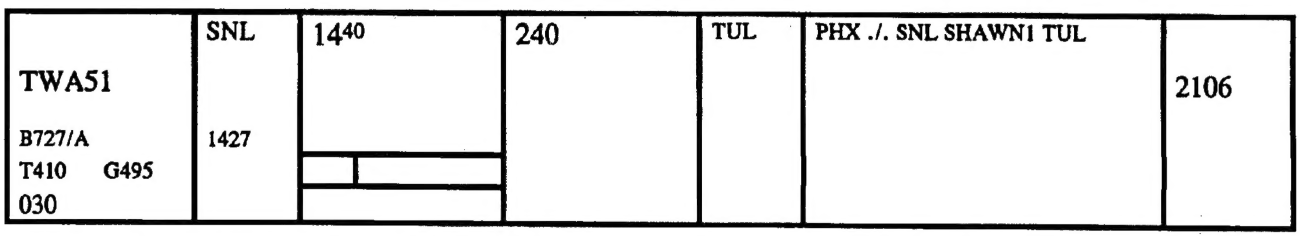

Figure 1. Example of a flight progress strip.

[1] In high traffic areas it is possible that more than two controllers will be responsible for a single sector.

strip by offsetting it from the others by lifting it slightly off the board and shifting it to the left or right. This activity may highlight an aircraft so that a planned control action will not be forgotten, thereby serving as extensions of the controller's memory (Jackson, 1989). In addition, repeated marking on the strips provides a historical record of the flight that may be beneficial (Hopkin, 1991; Weston, 1983) and this information will likely not be preserved in ISSS.

On the other hand, because flight strip management is clearly a time-consuming activity, the time spent maintaining the strips may be accompanied by costs as well as benefits. Casual reports from several controllers indicate that they do not need FPSs to safely control air traffic. They feel that the only tool necessary for air traffic control is the radar, and that any time spent away from the radar is time spent away from their primary task.

With the implementation of ISSS, the FPS bay will be replaced by a colored flight data display that allows computer-controlled manipulation of FDEs. ISSS has the capability to place FDEs into the suspense and active areas automatically, based on computer controlled hand-offs between sectors, and to automatically update flight information. Furthermore, unlike the current strip bay, the flight data display is not likely to display all pending flights and may not provide a visible history of aircraft data (e.g., speed and altitude). Only the most recent value may be stored, leaving previous values to be accessed by keyboard and/or trackball. Either of these changes may interfere with the controllers' memory for the airspace. As these changes imply, the flight data display provides a smaller workspace for the FDEs. If the number of FDEs exceeds screen capacity, constant scrolling may be required to examine the remaining FDEs. In sum, automation will force the controller to interact less directly and, perhaps less often, with the flight data.

Should interaction with FPSs be automated?

The goal of the current paper is to provide empirical data addressing the implications of FPS automation before it takes place. The logic of the current approach can be found in Vortac (1993) and Vortac, Edwards, Fuller, and Manning (1993). They recommended that automation of task components is likely to be successful if the task components can be segregated, that is, if they can be conducted in isolation from the rest of the system. Specifying which activities follow from others may reveal activities that controllers tend to segregate. If flight strip activity can be segregated, it is possible that automation will facilitate task and cognitive performance. On the other hand, if flight strip activity is inextricably intertwined with other controller functions, automation will probably not enhance performance.

This article reports a time-series analysis based on an observational study (Vortac, Edwards, Jones, Manning & Rotter, 1993) in which the behaviors of individuals and teams of controllers were categorized "on-line" while controlling simulated air traffic of high and low complexity[2]. The behavioral categories covered the range of activities that controllers perform on the strips: looking at them, writing on them, and manipulating them. Communication events and computer entries likely to be related to flight strip activity were also recorded. Time-series models were developed to predict flight strip activity from communication events, and computer interactions. Using time-series, rather than multiple regression, allows for the prediction of an action from an earlier action of the same type, while accounting for the autodependency of errors inherent in any model involving time (Ostrom, 1991).

Controller teams are assumed to perform an integrated set of activities. Each team member performs control actions at time t that are contingent upon the control action that occurred at time t-1. If this is true,

[2] Subjects also completed scenarios of medium complexity. However, because Vortac, Edwards, Jones, Manning, and Rotter (1993) found that medium-complexity scenarios have characteristics of both high- and low-complexity scenarios, only the results for high- and low-complexity are presented here.

and flight data activities are integrated among other control activity, the time-series models should show communication events and computer entries of each controller in the team predicting flight data activities of the other (R-side interactions with flight data are predicted by D-side activity, as well as other R-side activity; D-side interactions with flight data are predicted by R-side activity, as well as other D-side activity). If this is the case, the set of FPS activities performed by each controller should *not* be automated because each one forms an integral part of the whole.

On the other hand, if flight data activities are segregated then the time-series models should show that flight data activities of each controller are predictable by previous flight data activities performed by a single team member. For example, if D-side activity is primarily predicted by R-side activity then the D-side could be viewed as a task component controlled by the R-side. In this case, it is likely that the activities performed9 by the D-side controller can be automated without any decrement in performance for the R-side controller. This should be the case even when the controller is working singly.

In summary, the automatic management of FDEs will be the main characteristic changed by the implementation of ISSS. This change should have one of two consequences: (1) automation may relieve controllers of time-consuming activities that do not enhance job performance, or (2) automation of strip activity may deconstruct the integrated nature of the system, perhaps by interfering with the incidental cognitive benefits accrued by physically interacting with the strips (Hopkin, 1991).

METHOD

TESTING SITE AND SUBJECTS

The study was conducted at the Radar Training Facility (RTF) at the Federal Aviation Administration's (FAA's) Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma. Ten full-performance-level, FAA Academy instructors in the nonradar screen program served as subjects. They had worked operationally as en route controllers within the last two years (M = 7.0 months). The subjects were familiar with the airspace, but were not familiar with the particular scenarios used.

SCENARIOS

Five scenarios from each of two levels of complexity were selected from the *FAA Academy Scenario Guide.* Complexity is based on the number of departures, arrivals, en route aircraft control actions, equipment emergencies, special flights, and other coordination activities, in each scenario[3]. The low-complexity scenario lasted 30 minutes, with complexity rating ranging from 50-55%; the high-complexity scenario ranged from 90-95% complex and lasted one hour. The average number of FPSs used were 10.2 and 31.4 in low- and high-complexity, respectively. The high-complexity scenario was comparable to a situation in the field where a second controller (D-side) would likely provide assistance.

In each scenario, the strip bay was located to the right of the radar scope. The two observers sat behind and to the right and left of the controllers with computers on their laps. Two "ghost" pilots controlled the simulated aircraft and another assumed the communication functions of adjacent Centers and other air traffic control facilities.

APPARATUS

Verbal communication was recorded using a multi-track cassette recorder. One input channel included the pilots, adjacent Centers, and the controller (or the R-side member of a team, with the D-side communications recorded on a separate channel). In addition, each observer was recorded on their own input channel, allowing them to annotate their event recordings.

[3] Complexity was measured using the complexity worksheet found in the FAA's *Instructional Program Guide* (Appendix B, Section 3, Phase 8A for nonradar). Complexity was computed in the following way: departures got 5 points; arrivals, en route aircraft needing a control action, emergencies and radio failures each received 4 points; special flights got 3 points; en route aircraft not needing a control action got 2 points; and 1 point for each additional coordination action (e.g., point-to-point flight). More points indicates greater complexity. We selected scenarios from low and high complexity, corresponding to series 8 and 9, and 24 to 29, respectively, in the *Guide.*

A video camera was focused on the strip bays to record when writing and manipulating took place. Two notebook computers were used for the on-line data collection by the two observers. The time-lines generated by the observers were corrected off-line, due to an occasional misclassification, using the audio and video tapes.

PROCEDURE

Each subject participated twice; once as an individual and again as the R- or D-side member of a team. Teams participated approximately one month after the individuals were completed. On the last three days of individual controller participation, inter-rater reliabilities were calculated (Low = .83, High = .75). Because of the high reliability, the teams were coded using only two observers: one for the R-side and one for the D-side.

Each individual and team completed a counterbalanced sequence of scenarios. To ensure the same experimental history, each team member had completed the same sequence of scenarios when run individually. Subjects never controlled the same scenario twice.

Upon entering the RTF, subjects first completed a brief background sketch. They were then given the opportunity to organize the strip bay in preparation for the scenario. Subjects were provided with all the strips for the problem at this time and were instructed to control traffic as they would in the field.

Each experimental session lasted approximately 3 hours. Break periods between scenarios were approximately 20 minutes.

BEHAVIORAL CATEGORIES

For each scenario, the communication, FPS, and computer-related events listed in Table 1 were recorded, yielding a time-indexed behavioral record. As shown in Table 1, each main event listed in the left-hand column represents a composite of the individual actions listed in the right-hand column.

Communication events were categorized into *Controller Commands* (CCOM), *Controller Queries* (CQUERY), *Pilot Requests* (PREQ), *Sector Transitions* (SECTOR), and *Team Communication* (TEAM). FPS activities were categorized into *Looking at an FPS* (LOOK), *Writing on an FPS* (WRITE), and *Manipulating an FPS* (MANIP). Computer-related activities were categorized into *Updating the Computer Database* (UPDATE), *Obtaining Information From the Computer Database* (INFO), using the computer to aid in *Conflict Detection* (CONFLICT), and using the keyboard or trackball to initiate the *Hand-off* (HOFF) of an aircraft to an adjacent sector or facility.

Communication Events. A CCOM was a command issued by the controller to a pilot, whereas a CQUERY was a controller-initiated request for information from the pilot ("What is your altitude?"). A PREQ was a pilot-initiated request to the controller ("Can I fly direct to Tulsa?"). SECTOR involved interactions between the controller and adjacent sectors as well as other air traffic control facilities, primarily when aircraft were entering or exiting the sector. When a team participated, verbal communications between team members were also recorded (TEAM).

FPS Activities. The LOOK category included looks at both the active and suspense bays. Because a *look* obviously precedes other FPS activities, this category included only those looks that were not immediately followed by writing or manipulating. When coding teams, a *look* recorded on the D-side indicated a look at the radar scope, whereas a *look* on the R-side indicated a look at the strips. Multiple looks indicate that the controller looked away and then returned to look at the strips or the radar. The WRITE category included both verifications (e.g., a check mark placed by the altitude entry upon initial contact), and a change (e.g., crossing out and updating strip information). The MANIP category included any physical movement of the strip.

Computer-Related Activities. The computer that controlled the traffic simulation generated a summary of all computer-related control actions. From this summary, four additional computer-entry control actions were added to the data. The UPDATE category indicated that the controller updated flight information in the computer database, whereas the INFO category indicated that flight information was retrieved from the database. The CONFLICT category indicated the placing of a circle around an aircraft's location on the radar, visually representing a "bubble" of airspace surrounding that aircraft. The most important job in en route air traffic control is to main-

Table 1

Behavioral Categories and their Individual Actions

Main Event	Individual Actions
Controller Command (CCOM)	route change, speed change, altitude change, providing information (e.g., altimeters, VFR traffic), issuing clearance, other
Controller Query (CQUERY)	aircraft speed, altitude, route, other
Pilot Request (PREQ)	route change, speed change, altitude change, providing information (e.g., altimeters, VFR traffic), other
Sector Transitions (SECTOR)	turnover of control to adjacent sector, departure clearance, initial contact within sector
Team Communication (TEAM)	verbal and nonverbal communication between team members
Look (LOOK)	at active bay, at suspense bay
Write (WRITE)	verification of FPS information, change of FPS information
Manipulate (MANIP)	move FPS from suspense to active bay, sequence FPSs, offset FPS, flatten (undo offset) FPS, remove FPS from bay
Update Computer (UPDATE)	input assigned altitude, input interim altitude, change route
Obtain Computer Info. (INFO)	examine an aircraft's flight plan, display an aircraft's projected route on the radar scope
Conflict Detection (CONFLICT)	display a circle with a radius of five miles of airspace around a specified aircraft
Computer Hand-off (HOFF)	receive control from adjacent sector or facility

tain appropriate separation between all aircraft; the circle represented the boundary for minimum separation. Hand-offs (HOFF's) are initiated verbally and by computer. When an aircraft approaches the sector boundary or is to be transferred to another facility (e.g., approach control), the pilot is notified verbally and a sequence of keys is pressed to notify the adjacent facility of the HOFF.

Each of the above categories were used as predictors of flight strip activities. For controller teams, some of the abbreviated categories were preceded by an 'R' or 'D' indicating the controller responsible for the activity. For example, RWRITE represented the R-side controller writing on the strips and DWRITE represented the D-side controller writing on the strips. Categories that were not preceded by an 'R' or 'D' indicated that one controller was responsible for that activity. For example SECTOR was done by only the R-side controller.

RESULTS AND DISCUSSION

Autoregressive time-series models were used to predict flight strip activities (i.e., LOOK, WRITE, and MANIP). With these types of models, complications arise when pooling across subjects to estimate the overall time-series regression model. Various methods of estimating the pooled regression model exist. The Seemingly Unrelated Regression (SUR) was chosen because it can be used when pooling across subjects or when lagged dependent measures exist in the time-series model (see Appendix for additional details). For pragmatic reasons, the forward selection procedure recommended by Gallant and Jorgenson (1979) was used with the restriction that individual variables not explaining at least four percent of the total variance were eliminated from the models.

First, the low- and high-complexity scenarios were divided into 90-second time intervals. The number of responses for an FPS activity during interval t (Y_t) was predicted from the number of responses for the other p variables from that interval (X_{pt}), and the number of responses from the previous interval (Y_{t-1}). That is, $Y_t = f(X_{1t}, X_{2t}, ..., X_{pt}, Y_{t-1})$. SUR was used to develop separate models for each of the single and team conditions. Residuals were examined for each model and indicated that the data were well-fit by the model. Predictors are listed in order of contribution to the model. The models are divided into the categories, LOOK, MANIP, and WRITE. Each category will be discussed in turn.

The adjusted R^2 represents the proportion of variance accounted for by the model, corrected for the number of predictors included in the model. For each model, the degrees of freedom, adjusted R^2, χ^2, and corresponding p-value are reported. No reliable predictors were found for those models containing only an intercept.

LOOK. As shown in Table 2, looking was not predictable in either the single or team situations. Although three out of the four p-values were significant, indicating above chance predictability, only the high-

Table 2

Time-series Models: LOOK

Model		*df*	R^2adj	χ^2	*p*<
SINGLES					
LOW:	$\text{LOOK}_t = 2.07 - .30\ \text{SECTOR}_t$	1	.03	8.06	.0045
HIGH:	$\text{LOOK}_t = 1.34 + .20\ \text{LOOK}_{t-1}$	1	.04	16.59	.0001
TEAMS					
LOW:	$\text{RLOOK}_t = .75 + .17\ \text{TEAM}_t$	1	.03	3.53	.0603
HIGH:	$\text{RLOOK}_t = .38 + .26\ \text{RLOOK}_{t-1} + .12\ \text{TEAM}_t$	2	.11	21.27	.0001

Table 3

Time-series Models: MANIP

Model		*df*	R^2adj	χ^2	*p*<
SINGLES					
LOW:	$\text{MANIP}_t = .44 + .46\ \text{SECTOR}_t$	1	.15	35.27	.0001
HIGH:	$\text{MANIP}_t = .39 + .28\ \text{WRITE}_t + .25\ \text{SECTOR}_t$	2	.16	75.16	.0001
TEAMS					
LOW:	$\text{RMANIP}_t = .18 + .37\ \text{RMANIP}_{t-1}$	1	.12	11.58	.0007
	$\text{DMANIP}_t = 1.11$	—	0	—	—
HIGH:	$\text{RMANIP}_t = .16 + .54\ \text{RMANIP}_{t-1}$	1	.29	65.30	.0001
	$\text{DMANIP}_t = 1.44 + .46\ \text{SECTOR}_t$	1	.05	9.51	.0020

complexity RLOOK model accounted for over 4% of the variance. This model indicates that when the traffic situation is complex, the R-side controller is likely to look at the strips when communicating with the D-side controller. Also, if the R-side has looked at the strips once, he or she is likely to look again. This is the only LOOK model that accounts for over ten percent of the variance. Because no general conclusions can be reached by imposing meaning on one model, the LOOK models will not be discussed further. As indicated previously, DLOOK is not included in the table because it indicated a look to the radar scope and is therefore not considered a flight strip activity.

MANIP. The MANIP models are shown in Table 3. Although MANIP is predicted better than LOOK, the proportion of variance accounted for by each MANIP model is limited. Of these models, RMANIP in the teams-high condition accounts for the largest proportion of variability. The inclusion of RMANIP as the only predictor in the teams-high and -low conditions indicates that the best predictor of an R-side manipulation is another R-side manipulation. It would appear that when the R-side left the radar to manipulate the strips, he or she took one or more actions with them. In the teams-high condition, there is no agreement about what other activity is a predictor, other than RMANIP_{t-1}. Apparently a myriad of other activities covary with RMANIP, but none sufficiently often enough to be included as a predictor.

SECTOR is the only predictor in the singles-low and D-side high-team models, and SECTOR is accompanied by WRITE in the singles-high model. However, neither SECTOR nor WRITE is included in either RMANIP model, suggesting that the FPS activities performed by the R-side controller are qualitatively different than those performed by the D-side or by the controller working singly. Rather than being responsive to the actions of the R-side controller, which was seen above for RMANIP, D-side controllers are more responsive to the characteristics of the traffic situations, that is, aircraft entering and leaving the sector.

WRITE. In contrast to other FPS activities, Writing on FPSs is highly predictable. The average adjusted R^2, shown in Table 4, is much higher for these models than for either the LOOK or MANIP models (.34 vs. .05 and .15, respectively).

Inspection of these models suggests that there may be a common subset of predictors that can account for writing on the strips. WRITE (performed by an individual or R-side team member) is in five of the models

and SECTOR is in four. However, there are several other predictors, which when accompanied by SECTOR and/or WRITE may significantly contribute to the models' predictability (e.g., CCOM, UPDATE, MANIP, etc.).

In addition to SECTOR and WRITE, CCOM is included in two of the teams models. Futhermore, the combination of these three predictors represents a subset of all of the predictors in the teams models with only RINFO remaining. Note that CCOM does not show up as a predictor in either of the single controller models, perhaps because CCOM does not contribute to the predictability of writing on flight progress strips. However, this seems unlikely given its presence in the teams models. Another possibility is that CCOM covaried with other predictors and was selected out of by the forward selection procedure.

With these possibilities in mind we examined the singles data more closely to determine whether CCOM was closely competing for inclusion in the models. This inspection indicated that CCOM covaried with many of the predictors that are included in the single controller models. Specifically, CCOM was excluded by the forward selection procedure in favor of another predictor by an average R^2 of .02. Thus, when predicting writing on flight strips for individuals and teams of controllers, the most practical and parsimonious solution may be the following common subset of predictors:

$$\text{WRITE}_t = \text{SECTOR}_t + \text{WRITE}_{t-1} + \text{CCOM}_t .$$

This model was compared to each of the WRITE models in Table 4, without respect to predictor order, and found to account for as much variability as all but one of the original time-series models. Thus, the subset model *does* provide a parsimonious solution, sacrificing little predictability, and will therefore be the focus of the following discussion.

Beginning with D-side writing, for both high and low complexity, the common subset model is identical to the original DWRITE models. Thus, D-side writing can be predicted from the subset model's two R-side activities and sector transitions.

Substituting the subset model in the singles-low condition replaces UPDATE with a combination of CCOM and WRITE but does not significantly change the adjusted R^2. Similarly, the subset model did just as well as the original model at predicting RWRITE in the teams-low condition, in this case by replacing RINFO with a combination of SECTOR and CCOM: the .04 change in R^2 is not significant. In addition, substituting the subset model did not change the adjusted R^2 for the teams-high R-side condition (the .01 change is not significant). Thus, in singles-low, teams-low and -high R-side conditions, the common subset model predicted writing as well as either of the original models.

In the three models mentioned above (singles-low; teams-low R-side; teams-high R-side) the subset model adds one or two predictors not included in the original model. Although models with fewer predictors (like the original models) are generally preferred to multiple-predictor models, especially when they account for the same proportion of variability, the multiple-predictor subset model is preferred because it is has the most practical value. Moreover, the RWRITE single-predictor model, in the teams-high R-side condition, lacks predictive value because it does not indicate what led the R-side controller to begin the sequence of writing activity. For this reason, the subset model provides more information and is more useful than the original model, although the latter could be used without loss in predictability.

The final WRITE model is the singles-high condition. The subset model replaces MANIP with CCOM but again does not impact the adjusted R^2. Thus, in no case does the substitution of the subset model significantly reduce the predictability of writing on the FPSs.

Segregation. The inclusion of MANIP as a predictor of WRITE in the original singles-high model supports the idea that once controllers switch to the radar, they tend to perform FPS activities in clusters. This is also shown by comparing the singles-low and singles-high models in the MANIP category (see Table 3). WRITE is not included in the singles-low model, but is the best predictor in the singles-high model. This clustering of FPS activities as complexity increases supports the idea that individual controllers tend to segregate flight strip activities from radar activities, and to perform those activities in clusters (see also Vortac, Edwards, Jones, Manning, & Rotter, 1993; Vortac, Edwards, Fuller, & Manning, 1993). Perhaps this is why many of the individual controllers in the high-complexity

Table 4

Time-series Models: WRITE

Model		*df*	R^2adj	χ^2	*p*<
SINGLES					
LOW:	$\text{WRITE}_t = 1.49 + .68\ \text{SECTOR}_t + .58\ \text{UPDATE}_t$	2	.18	46.36	.0001
SUBSET:	$\text{WRITE}_t = .91 + .57\ \text{SECTOR}_t + .19\ \text{CCOM}_t + .19\ \text{WRITE}_{t-1}$	3	.19	50.86	.0001
HIGH:	$\text{WRITE}_t = 1.23 + .29\ \text{MANIP}_t + .28\ \text{WRITE}_{t-1} + .27\ \text{SECTOR}_t$	3	.23	118.86	.0001
SUBSET:	$\text{WRITE}_t = 1.11 + .12\ \text{CCOM}_t + .29\ \text{WRITE}_{t-1} + .40\ \text{SECTOR}_t$	3	.19	90.96	.0001
TEAMS					
LOW:	$\text{RWRITE}_t = .26 + .55\ \text{RWRITE}_{t-1} + .94\ \text{RINFO}_t$	2	.38	48.30	.0001
SUBSET:	$\text{RWRITE}_t = .03 + .62\ \text{RWRITE}_{t-1} + .20\ \text{SECTOR}_t + .04\ \text{RCCOM}_t$	3	.34	42.11	.0001
LOW:	$\text{DWRITE}_t = .92 + .56\ \text{RCCOM}_t - .67\ \text{RWRITE}_t + .56\ \text{SECTOR}_t$	3	.48	75.21	.0001
SUBSET:	$\text{DWRITE}_t = .92 + .56\ \text{RCCOM}_t - .67\ \text{RWRITE}_t + .56\ \text{SECTOR}_t$	3	.48	75.21	.0001
HIGH:	$\text{RWRITE}_t = .24 + .60\ \text{RWRITE}_{t-1}$	1	.36	89.21	.0001
SUBSET:	$\text{RWRITE}_t = .12 + .60\ \text{RWRITE}_{t-1} + .08\ \text{SECTOR}_t -.002\ \text{CCOM}_t$	3	.35	90.29	.0001
HIGH:	$\text{DWRITE}_t = 1.49 + .41\ \text{RCCOM}_t - .50\ \text{RWRITE}_t + .48\ \text{SECTOR}_t$	3	.38	99.22	.0001
SUBSET:	$\text{DWRITE}_t = 1.49 + .41\ \text{RCCOM}_t - .50\ \text{RWRITE}_t + .48\ \text{SECTOR}_t$	3	.38	99.22	.0001

scenario requested D-side assistance: They felt that they did not have time to perform the strip activities and when they took the time they tried to catch up. For these controllers it became increasingly difficult to switch roles between the FPSs and the radar, whereas within a team these roles are naturally separated.

Computer interactions also appear to change as a function of complexity. Although these predictors only entered into three of the models (MANIP: teams-low R-side; WRITE: singles-low, teams-low R-side), they always appeared in low-complexity situations. Controllers may segregate, or severely restrict, unnecessary computer interactions when the traffic situation gets complex. It is possible that performing any control activity not directly associated with observing the radar might reduce performance in complex situations.

Another indicator that controllers tend to segregate flight strip activities is that D-side activites are never included as a predictor. In all situations, R-side activities or computer interactions predicted both R- and D-side activities. This suggests that D-side activities truly support actions performed by the R-side.

Single versus Team activities. Once again, the single controller models and the D-side controller models share several predictors. For a given level of complexity, the D-side models use the same set of predictors as the single models. (Recall that RCCOM and RWRITE in the DWRITE low model replaces UPDATE in the singles-high model without any loss of predictability.)

The subset model can also be applied to the singles-high, singles-low, and D-side high MANIP models. In each case, MANIP is triggered by some configuration of the subset model predictors. R-side manipulations, on the other hand, were not predicted by any of the subset model predictors.

CONCLUSIONS

The aim of this study was to examine the current role of FPSs in en route air traffic control by determining which control actions reliably lead to FPS activity. The most predictable flight strip activity was writing, however, manipulating flight strips was also modestly predictable. There were generally three things that led to writing on a flight strip: (1) a sector transition, (2) a controller command, and (3) prior writing on the strips.

Flight strip activities are not as integrated into the overall control of air traffic as one might suspect. The activities performed by the R-side controller predicted the strip activities of both the R- and D-side controllers. When a team was responsible for a sector, a D-side activity never entered into any models. R-side control actions influence flight strip activities of both the R- and D-side, but D-side control actions rarely influence flight strip activities performed by the R-side. Thus, with regard to flight strip activities, when two controllers are responsible for a single sector, their relationship is not one of mutual exchange as "team" implies. Consequently, it is possible that flight strip activities performed by the D-side controller can be automated without any decrement to R-side performance (Vortac, 1992). On the other hand, if the team performed a more integrated set of flight strip activities, this would not be the case.

Together with the cognitive and performance analysis of Vortac, Edwards, Fuller, and Manning (1993), the above conclusions imply that automation of the FPS activities may enable an individual controller to control the same amount of aircraft with less effort, and therefore be better prepared to manage the increase in air traffic expected in the coming decades.

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Appendix A

Autoregressive time-series regression models differ from basic regression models in two fundamental ways: 1) time is included in the model (i.e., $Y_t = \hat{a} + \hat{b} X_t + e_t$), and 2) the error terms need not be independent, as they are assumed to be in the basic regression model.

According to Ostrom (1991), the dependence in the error terms does not bias the estimates $\hat{a}$ and $\hat{b}$, but does bias the variance estimates of $\hat{a}$ and $\hat{b}$, thereby affecting any test of significance. Further, Ostrom (1991, p.22) states that the variances of the estimates are typically underestimated when an autoregressive process is present. Thus, test statistics on the estimates are usually liberal and overrepresent the fit of the model when non-autoregressive time-series models are used. This means that when the autoregressive process is not taken into account, the R^2 values produced by the models are typically too high and the probability of rejecting the model is greater than the predetermined by the experimenter.

Additional complications arise when pooling across subjects to estimate the time-series regression model. Various methods of estimating the pooled regression model exist and the selected model of estimation must take into account the random nature of subjects (Sayrs, 1989). Seemingly Unrelated Regression (SUR) is a random coefficient regression model that allows the relationship between the criterion and predictors to differ across subjects while remaining constant for a given subject (Zellner, 1962). SUR accommodates individual subjects by allowing a separate $\hat{a}$ for each subject. We used SUR in our analyses for this reason.

Finally, because the time-series models also include lagged values of the dependent variable (i.e., $Y_t = \hat{a} + \hat{b}1 X_t + \hat{b}2\, Y_{t-1} + e_t$), the parameter estimates, $\hat{a}$ and $\hat{b}$, may be inconsistent estimators of the population regression weights (Ostrom, 1991). Fortunately, SUR adjusts for lagged dependent variables, thereby avoiding the inconsistent estimator problem (Sayrs, 1989).

A forward selection procedure was used to determine the best predictor models for each of the dependent variables. However, the standard forward selection procedure cannot be used because it does not take into account the correlation in the errors. To account for this potential problem, the forward selection procedure used here is based on Gallant and Jorgenson (1979). They found that the least squares difference between the full and restricted model, adjusted for the correlation among the errors, is asymptotically a χ^2 with degrees of freedom equal to the difference in the number of parameters estimated in the full and restricted models (SAS, 1988).

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